CHAPTER 3

Incorporating measures of anthropogenic threat in regional conservation assessments: A case study based on South African mammals

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Abstract

Informed conservation decisions can only be made after assessing current threats to biodiversity. The inclusion of human demographic data as one potential measures of biodiversity threat is known to improve our understanding of threats. The present study examines six possible human threat variables and their impacts on mammal priority assessments in South Africa. These variables which were also combined into a “Combined Human Threat” (CHT) measure for each of the assessed taxa incorporated: 1) average human density; 2) human population growth rate changes; 3) a poverty index; 4) per capita income expressed as Gross Geographic Product (GGP)/capita; 5) infrastructure, with reference to the degree of urbanisation and road cover; and 6) percentage land area transformed and degraded. The potential influence of the six anthropogenic variables were evaluated with reference to three measures of mammalian richness, namely: 1) overall mammalian richness; 2) endemic mammal richness; and 3) threatened mammal richness. There were varying, but weak statistically significant correlations between the human threat variables and the three measures of mammalian richness. There was little variance found across the three measures of mammalian richness in the manner they were predicted by the anthropogenic variables, suggesting that the potential mammal richness and human-threat variables may be responding to a common driver such as primary productivity. However, this analysis highlighted various mammals that were also categorized as threatened in the 2004 regional IUCN Red List, as well as being under considerable threat due to human activities. Moreover, a number of other mammalian taxa, mostly within the Orders Rodentia and Chiroptera, not necessarily threatened, emerged as mammals vulnerable to human threat. In addition, our results revealed 16 Data Deficient (DD) mammals which experienced higher than average combined human threat values than all Threatened mammals from South Africa. It is therefore possible that these mammals may be under higher risk than indicated in the 2004 regional IUCN Red List, or that these mammals are well adapted to human dominated landscapes.

Key words: Anthropogenic activities, extinction threat, IUCN South Africa mammals

Introduction

Human actions threaten biological diversity at a global scale, and these sources of threat include taxon-specific threats such as exploitation, introduced taxa as well as various forms of ecosystem degradation e.g. land transformation, pollution etc. (World Resources Institute 2000). These threats disrupt and alter ecosystem structure and function (Sisk et al. 1994) and eventually leading to species' extinctions (Kerr & Currie 1995). Informed species conservation decisions can only be made after assessing the current state and threats faced by species in order to identify priority species for conservation. This forms only a part of a multi-faceted approach that can be used to set conservation priorities (Hannah et al. 1994; Sisk et al. 1994). Various studies have focused on assessing the state of species populations and a wide range of techniques such as IUCN Red List Criteria and Categories (IUCN 2001) have been developed and are routinely used for this purpose. However, it is only recently that human impacts have been incorporated into species threat status assessments (Mills et al. 2001; Harcourt & Parks 2003).

Various human activities, their effects on animal and plant taxa and the associated extinction vulnerabilities have been investigated (Kerr & Currie 1995; Thompson & Jones 1999; Cincotta et al. 2000; Ceballos & Ehrlich 2002; Harcourt & Parks 2003; Liu et al. 2003). Overall, these studies strongly suggest correlations between continental rates of habitat change and local species disappearances with levels of human activity (Cincotta et al. 2000; Balmford et al. 2001; Ceballos & Ehrlich 2002; Harcourt & Parks 2003, Luck et al. 2003; van Rensburg et al. 2004a).

It is critical to understand the relationship between human activity and biodiversity condition at national scales, as this allows the identification of local threatening processes and priority areas, and more specifically, specific taxa at risk of extinction (Chown et al. 2003; Liu et al. 2003). Species richness has been successfully used as a biodiversity surrogate in such assessments. These data are available and relatively easy to compile, and are often useful for prioritising areas of conservation importance (Fjeldså 2000). However, the relationship between human activities, mammal richness, and threats to species richness at a national level remain largely unclear. South Africa has several spatially explicit datasets of human demographic data (Central Statistical Service 1995; 1998; Fairbanks et al. 2001; Harcourt & Parks 2003), and a national assessment of human activity and species threat status can use such data.

Six human activity related variables (for which data are readily available) human population density, human population change, a poverty index; affluence measure (expressed as Gross Geographic Product (GGP)/capita), infrastructure and land transformation and degradation are widely acknowledged as threats to plant and vertebrate taxa in the study area and elsewhere (Macdonald 1991; James 1994; Kerr & Currie 1995; Cincotta et al. 2000; Ceballos & Ehrlich 2002; Harcourt & Parks 2003, Luck et al. 2003). While it is acknowledged that human activities are complex, and not entirely encapsulated in these six variables, these variables will allow for improved insight into the relationship between human activity and mammal species threat in South Africa.

Due to the strong correlations between human density, population growth, poverty, and environmental degradation, these factors are mostly reinforced by additional influences such as household dynamics, urbanization, technology, and political stability (World Resources Institute 2000; Liu et al. 2003; Rouget et al. 2003). It has however been demonstrated that as human populations grow, this results in declining agricultural productivity/capita, and this in turn, increases levels of rural poverty (Upkolo 1994). Consequently, rural populations migrate to urban areas (Upkolo 1994; World Resources Institute 2000) resulting an urban sprawls that generally lead to the complete transformation of relatively large urban fringes (Macdonald 1991; Cincotta et al. 2000; Liu et al. 2003). The combined forces of population demographics therefore, exert tremendous pressures on ecological systems in especially Africa and other developing areas of the world (Ukpolo 1994; Hanks 2000; Rouget et al. 2003; van Jaarsveld et al. 2005).

Human population density is considered a relatively good indicator of threat in the assessment of risk of species extinctions (Thompson & Jones 1999; Harcourt & Parks 2003) because vertebrate population declines are mostly concentrated in areas with either high human densities or with high human impact such as agricultural areas (Burgess et al. 2002; Ceballos & Ehrlich 2002; Araújo 2003).

In many countries, increasing poverty is closely related to high population density, which in turn exerts tremendous local pressure on biodiversity (Lucas & Synge 1981; James 1994). Consequently, poverty-stricken communities are forced to rely on surrounding resources for survival, which often leads to environmental degradation (James 1994). In addition, the relationship between per capita income (GNP) and environmental degradation has been shown to be complex (Naidoo & Adamowicz 2000). Per capita

GDP has also been shown to be closely correlated with the proportion of threatened mammals (Kerr & Currie 1995; Naidoo & Adamowicz 2001). Naidoo and Adamowicz (2001) reports that high GNP usually triggers excessive land conversion and resource exploitation, which increases the number of threatened taxa.

Changes in land-use and cover are important drivers in the broader context of global environmental change. The impact of anthropogenic land use and the loss of species is often directly related to the proportion of the area either degraded, transformed and/or fragmented (Pfab & Victor 2002; Melles et al. 2003; Theobald 2003). Theobald (2003) found areas with more than 15% development to be highly fragmented and, therefore, impact negatively on species and resulting in local extinctions. Similarly, road networks have been implicated to have disproportionate effects on species, their construction and maintenance significantly altering and fragmenting natural habitats and landscapes (Macdonald 1991; Reyers 2004).

Both natural and anthropogenic factors are important in determining a taxon’s risk of extinction (Kerr & Currie 1995) and consequential its priority for conservation. The use of regional IUCN Red List (RL) assessments (Friedmann & Daly 2004) which provide an assessment of species extinction risks, in conjunction with measures of anthropogenic impacts, may allow for more informed decisions about the conservation priority of South African mammals (Hannah et al. 1994; Sisk et al. 1994; Harcourt & Parks 2003). The current study is aimed at investigating the relationship mammal richness measures (including endemic and threatened mammal richness) and measures of anthropogenic threat to assess the conservation status of South African mammals across the country.

Methods

South African Mammal data

Regional IUCN Red List assessment information (Friedmann & Daly 2004) for 249 currently recognized extant South African terrestrial mammals was included in the current study in addition to their respective distribution information. Two types of distribution data were used for analysis: presence records and extent of occurrence range maps (Freitag & van Jaarsveld 1995; Keith 2004). These data sets were based upon presence data (Frietag & van Jaarsveld 1995; updated for Friedmann & Daly 2004), and the extent of occurrence data (range maps; Keith 2004) that can be regarded as the potential distribution of species. The use of presence data in conjunction with distribution range maps have been proven to be the most effective way of mapping mammal biodiversity in South Africa, circumventing potential data bias of large mammals being restricted to conservation areas as well as additional data constraints (Freitag & van Jaarsveld 1995; Gelderblom & Bronner 1995). All distribution data were generalised to a common resolution of the quarter degree squares (QDS – an area of ~ 625km^2).

Three measures of mammalian richness were derived from the distribution data. First, a measure of overall mammal richness (OMR) for South Africa was collated at the QDS level. The second included a literature-derived measure (Skinner & Smithers 1990; Siegfried & Brown 1992; Friedmann & Daly 2004) of South African endemic mammal richness (EMR). The third included a measure of South African threatened mammal richness (TMR) based on all mammals highlighted as “Threatened” by Friedmann & Daly (2004) (categorised as Vulnerable (VU), Endangered (EN), or Critical Endangered (CR)). As suggested by Rebelo & Tansley (1993), both EMR and TMR were standardized and corrected for total mammal richness in order to derive a standardized EMR and TMR at a QDS scale.

South African anthropogenic data

Six anthropogenic variables were used in the present study including: 1) human population density, 2) human population growth rate change 3) a poverty index; 4) affluence measure 5) infrastructure, and 6) the degree of land transformation and degradation. Human population density, human change, poverty, and affluence data were derived from magisterial district data (Central Statistical Service 1995, 1998), while all land-cover and transformation data were collated from the National Land-Cover database (Fairbanks & Thompson 1996). In order to standardize with the mammal distributional data, data were converted to a spatial scale at the QDS level using ESRI ArcView GIS 3.2. Consequently, most human demographic and impact data represent weighed averages/QDS.

The 1996 South African population census data (Central Statistical Service 1998) were used to estimate the weighted average population density per QDS (Human Density - HD). HD was denoted as the average number of people/km^2 within each QDS. The average percentage increase/decrease of human population per QDS (human growth rate change - HC) over the period 1996 to 2001 (Central Statistical Service 1998; Rouget et al. 2004) was used as a direct proxy for the impact of human population growth on the environment.

A poverty index (Economic Poverty (EP)) was estimated as the proportion of people per municipality earning less than R200 per month (Central Statistical Service 1998). A United Nations Development Programme South Africa (2003) report for South Africa indicated that people earning less than R354 per month could be regarded as earning below the poverty line. The census data uses broad categories of which "less than R200/month" together with the "no income" category was regarded as earning below the poverty level. This allowed the computation of a weighted average of the proportion of people per QDS earning less than R200/month.

A measure of Economic Affluence (EA) denoted as the weighted average GGP/capita income per QDS, was based on Gross Geographic Product (GGP) obtained for all South African magisterial districts (Central Statistical Service 1995). GGP represents "the remuneration received by the production factors – land, labour capital and entrepreneurship for their participation in production within a defined area" (Central Statistical Service 1995). The Central Statistical Service (1995) provides 1994 estimates of GGP and remuneration of employees by magisterial district in South African Rand (R). This GGP data represents the finest-scale data available and was incorporated in the current analysis rather than GNP data as previously used by Kerr & Currie (1995).

Current infrastructure data were extracted from the National Land-Cover database (NLC) (Fairbanks & Thompson 1996). One of the land-cover variables included in the current study was the percentage of QDS' covered by road and urbanised areas (Land — cover – Roads and Urban (LRU). A buffered road network for South Africa was obtained from Reyers et al. (2001) representing various buffered road types in South Africa. The extent of the urban area was extracted from all types of "Urban/built-up land" land cover type (= land cover type 24-30; Fairbanks & Tompson 1996) in the NLC database.

An additional land-cover variable, the degree of Land — cover – Transformed and Degraded (LTD) was also extracted from the NLC database. Fairbanks et al. (2001) grouped 31 land-cover classes in

South Africa into three categories, namely, Natural, Transformed, and Degraded land-cover types. The area transformed and degraded in each QDS was calculated to represent a measure of LTD.

Statistical Analysis

By collating the six measures of human impact on the environment used in the present study, a Combined Human Threat (CHT) measure was derived for each QDS in South Africa. Initially, the QDS data for South Africa were ranked according to each of the six separate anthropogenic measures. Subsequently, an averaged CHT rank score for each mammal species was based on the average human impact measure ranks throughout the species' QDS range. All six anthropogenic variables were ranked and weighted equally in calculating CHT. The relationship between CHT and mammal distribution in South Africa was assessed in order to derive an average CHT rank for each of the 249 mammals with reference to their respective QDS distributional ranges.

All three measures of richness (OMR, EMR and TMR) and the six-anthropogenic variables (HD, HC, EP, EA, LRY LTD, and CHT) were log-transformed for statistical analyses. Kruskal-Wallis Analysis of Variance (ANOVA) by Ranks and Spearman's *R* Rank order correlations (Zar 1996) were used to test for statistical differences and correlations, respectively, between measures of mammal richness and CHT and the six anthropogenic variables. Independent Generalized Linear Models (GLZ; McCullagh & Nelder 1989) were used to assess the relationship between each of the three measures of mammal richness and the six anthropogenic variables.

Because the measures of mammal richness were in the form of counts, a Poisson distribution with a logarithmic link function was used in the GLZ (Maggini, Guisan & Cherix, 2002). A goodness of fit test (a deviance statistic), which explains the proportion of deviance for each model in the GLZ (McCullagh & Nelder 1989) was independently used to assess the relationship between: 1) the three measures of mammal richness, namely, OMR, EMR, and TMR; 2) the six anthropogenic variables, namely, HD, HC, EP, EA, LTD, and CHT; 3) mammal species, IUCN Red List categories, human pressures, and threat. All statistical analyses were based on analytical sub-routines in STATISTICA version. 6 (StatSoft 2001).

Results

South African mammal richness

The three measures of mammal richness, namely, OMR, EMR, and TMR were all significantly different from each other (Kruskall Wallis $H_{3,\ 5871}$ = 12491; $P < 0.001$). OMR was significantly correlated with EMR (Spearman's $R = 0.36$; $n = 1955$; $P < 0.05$), with the regression model explaining approximately 67.83% (Pearson ^{2} = 503.74; d.f. = 1955; $P < 0.001$) of the total variance. Similarly, OMR and TMR were strongly and significantly correlated (Spearman's R = 0.64; n = 1955; $P < 0.05$), with the regression model explaining approximately 56.56% (Pearson ^{2} = 658.62; d.f. = 1955; $P < 0.01$) of total variance. The relatively strong correlations suggest a strong influence of OMR in explaining endemic and threatened mammal counts in South Africa.

Anthropogenic measures

Areas of high combined human threat (CHT) were generally found throughout the Western Cape, areas of the Eastern Cape, Free State North West Province and Gauteng (Figure 1). HD and HC were high in the large metropolitan areas such as those in the Western Cape, Gauteng, and KwaZulu-Natal Provinces (Figure 2a-c). Gauteng Province shows the highest average anthropogenic variables except for EP and EA. KwaZulu-Natal Province presented the highest EP, North-West Province the highest EA, with Northern Cape Province yielding very low EA values throughout the province. While areas with high LRU are in Gauteng, areas with high LTD are evident in the Western Cape, Eastern Cape, North-West, and Free State Provinces (Figure 2a-c).

CHT ranking and the six anthropogenic variables were all strongly significantly different from each other (Kruskall Wallis $H_{6,\ 11601}$ = 7307.40; $P < 0.001$), with varying negative and positive correlations between them (Table 1). Larger Spearman's R-values indicate a strong dependence of the respective variables on one another. In most cases, EA was negatively correlated with other anthropogenic variables (Table 1), suggesting a weak dependence between EA and the other anthropogenic variables. EP and HC were the only variables that were not correlated.

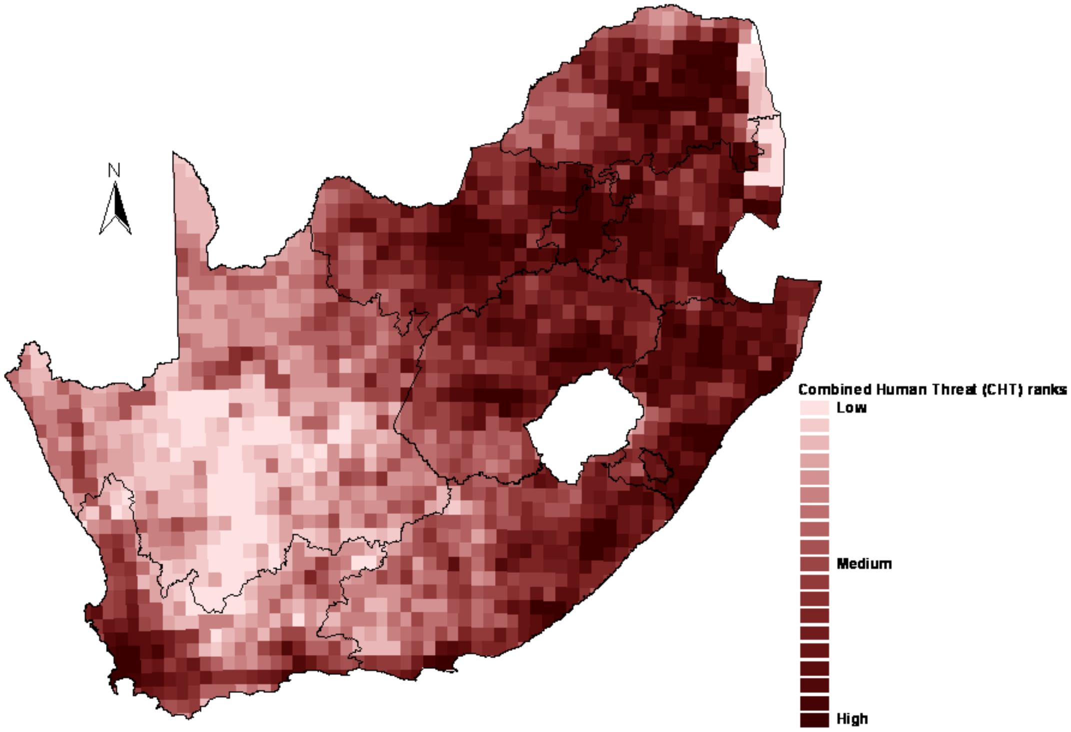

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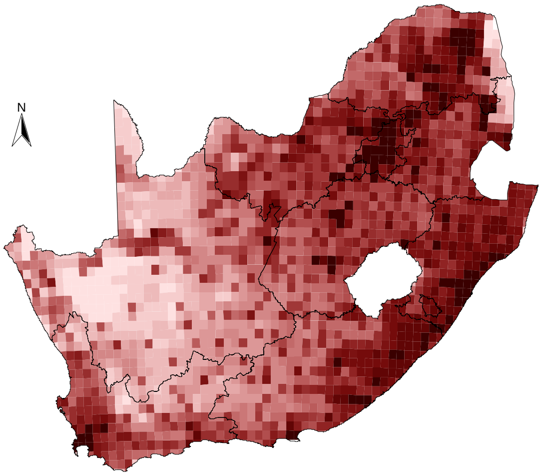
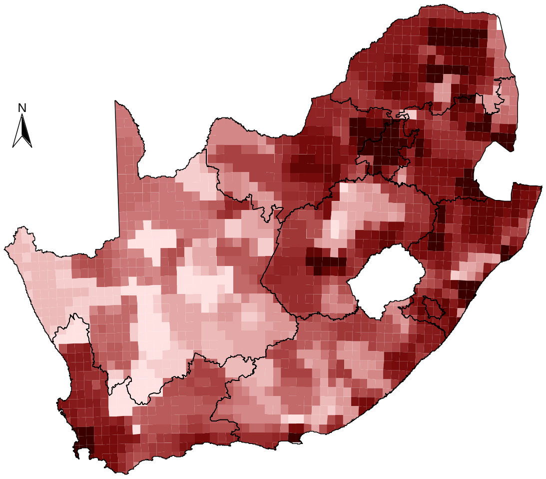
Figure 1. Spatial representation of the combined human threat (CHT) ranked QDS across the South African landscape, based on six anthropogenic measures, human density, human population rate change, poverty, affluence, infrastructure and area transformed or degraded.

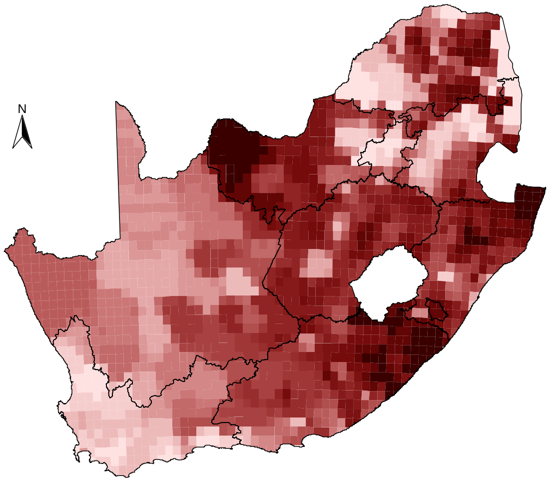


HD

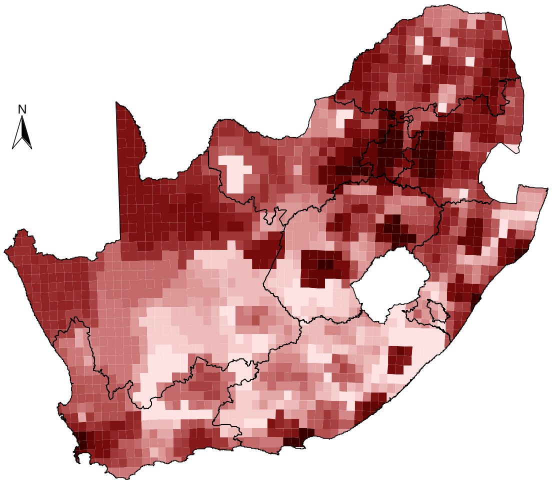


HC

Figure 2a. Spatial representation of 1) human population density (HD), 2) human growth rate change (HC), which were used in combination of the other anthropogenic ranks to calculate a human threat measure (CHT). High impacts are in darker colours and light impacts in light shades.

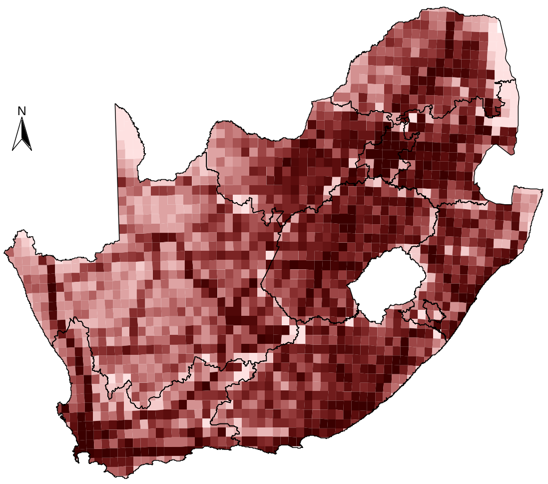


EP

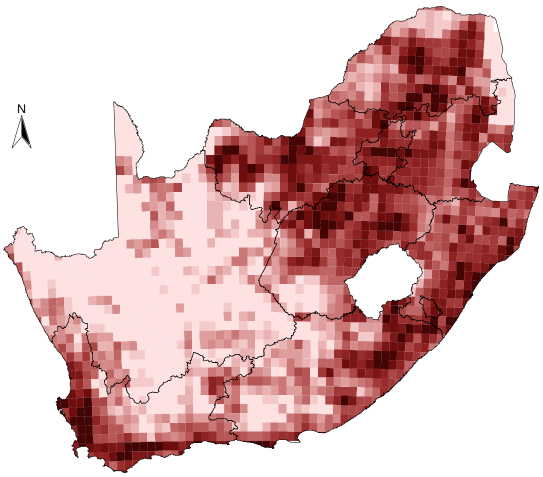


EA

Figure 2b. Spatial representation of 3) poverty index (economic poverty (EP); 4) measure of economic affluence (EA) denoted as the weighted average GGP/capita (EA) which were used in combination of the other anthropogenic ranks to calculate a human threat measure (CHT). High impacts are in darker colours and light impacts in light shades.



LRU



LTD

Figure 2c. Spatial representation of 5) infrastructure (road and urbanised areas (LRU)), and 6) the degree of land transformation and degradation (LTD), which were used in combination of the other anthropogenic ranks to calculate a human threat measure (CHT). High impacts are in darker colours and light impacts in light shades.

Table 1. Spearman Rank order correlation (*R* – values) for the six-anthropogenic measures. Abbreviations are as follows: HD = human density, HC = human growth rate change (HC), EP = economy poverty, EA = economy affluence, LRU = land use roads and urbanization, LTD = land use transformed and degraded, and CHT = combined human threat. All bold values indicate a statistical significance of $P < 0.05$. Values with superscript **ns** is not statistically significant correlated.

	HD	**HC**	**EP**	**EA**	**LRU**	**LTD**
HD	**1.00**					
HC	**0.54**	**1.00**				
EP	**0.34**	0.003^{ns}	**1.00**			
EA	**-0.86**	**-0.37**	**-0.48**	**1.00**		
LRU	**0.57**	**0.26**	**0.10**	**-0.49**	**1.00**	
LTD	**0.73**	**0.54**	**0.25**	**-0.59**	**0.42**	**1.00**
CHT	**0.88**	**0.66**	**0.40**	**0.35**	**0.65**	**0.82**

Relationships between South African mammal richness and anthropogenic impact

OMR, the six anthropogenic variables, and CHT were all significantly correlated (Table 2). OMR was positively correlated with HD, HC, LRU, LTD, as well as with CHT. EP was weakly correlated with OMR. The GLZ model generally fitted poorly with six anthropogenic variables, with OMR accounting for very little of the percentage deviance explained (< 6.86 %; Table 2), and CHT explaining 12.26% of the deviance.

EMR and the six anthropogenic variables were all weakly correlated with each other (Table 2), and the independent anthropogenic variables did not substantially explain the variance found in EMR (Table 2), with CHT accounting for only 16.71% of the variance. Both EP and EA were weakly negatively correlated with EMR, with EP accounting for a small proportion of the variance. EA and EMR were negatively correlated with EA accounting for only 0.52% of the variation.

On the other hand, TMR and the six anthropogenic variables were all weakly significantly correlated, except for EP (Table 2). EA and TMR were negatively correlated, with EA contributing little to the total variance (Table 2). EP and LRU were not significantly correlated, while very little significant deviance (< 3.54%) was evident between the remaining anthropogenic variables (Table 2). CHT explained the highest proportion (17.09%) of the deviance observed within TMR.

Relationship between mammals and human activity measures

With reference to the recent regional IUCN Red List assessment (Friedmann & Daly 2004), 50 of the 249 terrestrial mammals included in the present analysis were identified as threatened (i.e., CR, EN, and VU)). Generally, CHT and the six anthropogenic data show considerable variation within each of the IUCN Red List categories (Table 3). The exclusion of large bodied mammals (those most likely to be restricted to conservation areas) from the analysis did not affect the outcome between mammal richness measures and the human variables (Keith unpublished data). Mammals categorized as CR taxa did not show the highest relationship with either CHT or the six anthropogenic variables. HD and LRU showed the highest relationship with all IUCN categories. The anthropogenic values for the components CHT and EP were significantly different when inter threat (CR-, EN-, and VU-assessed mammals) comparison were

Table 2. Spearman Rank (*R* - values) and *P* value, as well as the generalised linear model (a Poisson error distribution, using a Log Link function (McCullagh & Nelder 1989)) parameters for between overall mammal richness (OMR), endemic mammal richness (EMR), between threatened mammal richness (TMR) as well as combined human threat (CHT); human density (HD); human population rate change (HC); economy poverty (EP); economy affluence (EA); infrastructure (LRU) and land use transformed and degraded (LTD). (Statistical significance: *** = P < 0.001; ** = P < 0.01; * = P < 0.05; ns = not statistically significant)

	OMR Spearman *R* value	OMR Explained Deviance	*OMR Pearson* ^{2}	EMR Spearman *R* value	EMR Explained Deviance	*EMR Pearson* ^{2}	TMR Spearman *R* value	TMR Explained Deviance	*TMR Pearson* ^{2}
CHT	0.41 *	12.26 ***	38990.8	0.41 *	16.71 **	5299.3	0.4 *	17.09 **	5440.7
HD	0.43 *	5.7 **	43797	0.19 *	2.83 **	5497.66	0.14 *	3.54 **	5507.44
HC	0.4 *	6.86 **	43147.7	0.12 *	3.16 ***	5428.08	0.19 *	3.47 ***	5501.54
EP	0.05 *	0.03 *	45260.9	-0.13 *	6.06 **	4711.67	-0.28 ^{ns}	0.16 ^{ns}	5494.7
EA	-0.33 *	0.02 **	45218.1	-0.17 *	0.52 **	5515.78	-0.11 *	0.45 **	5438.64
LRU	0.21 *	2.37 **	45478.9	0.19 *	5.77 **	5279.96	0.06 *	0.18 ^{ns}	5537.99
LTD	0.3 *	2.17 **	45280.8	0.17 *	5.07 **	5084.94	0.14 *	1.13 ***	5586

Table 3. Layout of average human variables (Mean ± Standard Error) for the IUCN Red List assessment of all mammal taxa under consideration for the current study. IUCN Red List categories comprise of Critically Endangered (CR), Endangered (EN) and Vulnerable (VU) (Threatened categories), Near Threatened (NT), Data Deficient (DD) and Least Concern (LC). Human variables included Combined Human Threat measure (CHT) as well as the six human variables (HD = human density ($\overline{X}$ people/km^2), HC = human growth rate change ($\overline{X}$ % increase/decrease of people), EP= economy poverty (proportion of people earning < R200/month), EA = economy affluence (Rand (GGP) x R1 000 000), LRU = infrastructure (% area under urban or road cover), LTD = land use transformed and degraded (% area transformed or degraded). Values in bold indicate variable that is higher than the average IUCN threatened "average" value.

Red List assessment	*N*	CHT	HD	HC	EP	EA	LRU	LTD
CR	10	856.88 ± 328.27	81.19 ± 125.7	4.85 ± 14.45	57.97 ± 9.41	102.82 ± 153.55	7.75 ± 6.32	26.62 ± 18.87
EN	15	1048.59 ± 173.45	59.09 ± 30.67	9.42 ± 4.94	66.91 ± 8.88	738.59 ± 256.1	6.4 ± 1.97	30.63 ± 10.63
VU	25	982.3 ± 173.86	67.52 ± 68.46	9.74 ± 7.45	62.74 ± 9.34	833.48 ± 591.3	6.47 ± 2.97	30.19 ± 12.49
Threatened	50	970.64 ± 218.45	68.76 ± 74.34	8.49 ± 24288.42	62.69 ± 9.56	856.46 ± 797.83	6.72 ± 3.61	29.6 ± 13.0
NT	36	904.2 ± 197.29	44.64 ± 27.66	8.48 ± 7.63	60.56 ± 6.81	743.26 ± 244.76	5.88 ± 1.91	23.63 ± 10.74
DD	30	**978.65 ± 122.74**	53.8 ± 20.39	**10.64 ± 3.27**	62.35 ± 5.1	799.36 ± 230.87	6.54 ± 1.42	26.78 ± 5.89
LC	133	878.99 ± 151.02	41.55 ± 21.33	8.33 ± 5.63	60.31 ± 4.02	736.94 ± 211.49	6.15 ± 1.2	22.74 ± 7.91
Average	249	914.34 ± 175.51	48.73 ± 39.96	8.7 ± 6.47	61.14 ± 6.13	766.79 ± 407.66	6.27 ± 2.04	24.74 ± 9.8

undertaken. Similarly, a comparative analysis between threatened (i.e., CR, EN, and VU) and not threatened (i.e., NT, DD, and LC) assessed mammals indicated that only CHT and LTD were significantly different (Table 4). Of interest though is the relatively low average CHT value for the Critically Endangered (CR) mammals (Table 3). These low values can be attributed to the fact that CR assessed mammals were largely restricted to areas where the current study identified low anthropogenic impact in terms of low HC, EP, and EA (e.g. riverine rabbit, *Bunolagus monticularis* and Visagie's golden mole *Chrysochloris visagiei*).

However, when the means of CHT and anthropogenic variable values of threatened mammals were used as a threshold (average value calculated from the Threatened categories for each of the six human threat variables and CHT), mammals categorized as DD showed higher CHT and HC values than the average CHT and HC values for mammals categorized as Threatened. Neither CHT nor any of the six anthropogenic variables were statistically significantly different from each other when DD and threatened mammals were compared (Table 4). When Orders were compared, CHT, HD, and LTD differed significantly from each other (Table 4). When individual CHT rankings for all DD mammals were used, 15 of the 30 DD mammals showed a higher mean CHT ranking than that of the threatened mammals (average CHT = 977.10) (Table 5; Table 6).

When South African mammals were ranked with reference to CHT, various non-threatened and some threatened mammals occurring in areas of high human impact were identified (Appendix 2). From this ranking, some NT-, DD-, and LC-categorized mammals were ranked highly, and these mostly consisted of members of the Orders Insectivora, Rodentia, and Chiroptera. The top five ranked mammals included: 1) the Pretoria sub-population of Juliana's golden mole*, *Neamblysomus julianae* (CR A2c; B1ab (i-v)+B2ab (i-v)); 2) Large-eared free-tailed bat, *Otomops martiensseni* (VU D2); 3) Gunning's golden mole*, *Neamblysomus gunningi* (EN B1ab(i-iv) B2ab(i-iv)); 4) Nyika climbing mouse, *Dendromus nyikae* (NT), 5) and Sclater's forest shrew*, *Myosorex sclateri* (EN B1b(ii,iii), c(iv)+2b(ii,iii), c(iv)). Three of these five top-ranked mammals are endemic to South Africa (denoted by *). Some of the highly threatened Red List species, Visagie's golden mole, *Chrysochloris visagiei* (CR D) and the riverine rabbit, *Bunolagus monticularis* (CR C2a(i), E) (both endemic) received very low respective CHT scores.

Table 4. Statistical analysis (Kruskall Wallis *(H)* and Mann Whitney *U*) test statistics for comparisons between 1) three IUCN Red List categories comprising of Critically Endangered (CR), Endangered (EN) and Vulnerable (VU) (threatened categories), 2) Threatened taxa and not threatened taxa (Near Threatened (NT), Data Deficient (DD) and Least Concern (LC)), 3) Threatened taxa and DD taxa, and 4) comparisons between 13 Orders (Artiodactyla, Carnivora, Chiroptera, Hyracoidea, Insectivora, Lagomorpha, Macroscelidea, Perissodactyla, Pholidota, Primates, Proboscidea, Rodentia, and Tubulidentata). Analysis included combined human threat measure (CHT) as well as the six human variables (human density (HD); human growth rate change (HC); economy poverty (EP); economy affluence (EA); infrastructure (LRU) and land use transformed and degraded (LTD)). (Statistical significance: *** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$; ns = not statistically significant).

Variable	CR, EN and VU *Kruskal-Wallis H* $_{(2; 50)}$	Threatened vs. Not threatened *Mann Whitney U*	Threatened vs. Data Deficient *Mann Whitney U*	Between all Orders *Kruskal-Wallis H* $_{(12; 249)}$
CHT	6,65 **	3386.0 ***	668.0 ^{ns}	19.90 *
HD	2.59 ^{ns}	4401.000 ^{ns}	713.0 ^{ns}	20.72 *
HC	1.27 ^{ns}	4534.5 ^{ns}	688.0 ^{ns}	16.77 ^{ns}
EP	8.28*	4366.0 ^{ns}	742.0 ^{ns}	7.62 ^{ns}
EA	1.41 ^{ns}	4249.5 ^{ns}	573.0 ^{ns}	11.71 ^{ns}
LRU	0.67 ^{ns}	4958.0 ^{ns}	691.0 ^{ns}	16.90 ^{ns}
LTD	4.52 ^{ns}	3284.0 ***	598.0 ^{ns}	23.86 **

Table 5. Layout of average Combined Human Threat (CHT) rank and six human variables as calculated for all terrestrial mammal Orders (human density (HD); human growth rate change (HC); economy poverty (EP); economy affluence (EA); infrastructure (LRU) and land use transformed and degraded (LTD)). Human Density (HD); Human Increase (HI); Economy Poverty (EP); Economy Affluence (EA) (x R1 000 000); Land use Roads and Urbanization (LRU) and Land use Transformed and Degraded (LTD). Values in bold indicate to an Order with specific human variable that is higher than the average IUCN threatened "average" as calculated in Table 3

Order	**CHT**	**HD**	**HC**	**EP**	**EA**	**LRU**	**LTD**
Artiodactyla	946.85 ± 108.71	48.6 ± 20.45	**10.48 ± 4.44**	61.39 ± 5.17	774.57 ± 189.07	6.35 ± 1.11	25.76 ± 6.11
Carnivora	885.6 ± 94.34	39.61 ± 14.05	8.58 ± 3.91	60.59 ± 2.42	732.57 ± 151.89	6.04 ± 1.1	22.28 ± 4.93
Chiroptera	957.11 ± 150.5	61.67 ± 46.65	**9.55 ± 5.97**	61.29 ± 6.26	825.41 ± 330.12	6.1 ± 1.77	27.09 ± 10.89
Hyracoidea	957.82 ± 130.42	58.09 ± 31.52	**10.18 ± 5.73**	62.6 ± 6.93	633.81 ± 28.94	6.66 ± 1.65	27.46 ± 7.83
Insectivora	**975.58 ± 196.87**	63.44 ± 67.85	**10.97 ± 7.82**	60.84 ± 8.83	**970.99 ± 901.42**	**7.66 ± 3.73**	29.28 ± 8.68
Lagomorpha	814.35 ± 215.58	33.48 ± 27.4	5.09 ± 8.37	60.41 ± 3.22	648.35 ± 351.59	6.07 ± 1.17	18.33 ± 10.26
Macroscelidea	773.31 ± 214.23	25.9 ± 22.9	4.77 ± 7.13	60.4 ± 7.43	631.33 ± 286.25	5 ± 1.55	16.13 ± 10.56
Perissodactyla	835.46 ± 223.72	29.57 ± 26.12	**8.89 ± 7.76**	58.95 ± 3.89	635.89 ± 260.59	5.49 ± 1.26	19.88 ± 11.08
Pholidota	959.25 ± 0	32.88 ± 0	**10.2 ± 0**	61.92 ± 0	676.55 ± 0	5.1 ± 0	25 ± 0
Primates	**1006.75 ± 89.95**	55.7 ± 16.6	**9.64 ± 4.95**	**66.71 ± 9.51**	670.19 ± 341.11	6.03 ± 1.98	28.04 ± 4.2
Proboscidea	896.02 ± 0	36.41 ± 0	**12.26 ± 0**	58.29 ± 0	676.18 ± 0	4.35 ± 0	19.14 ± 0
Rodentia	871.77 ± 215.2	41.61 ± 34.42	6.67 ± 7.34	61.06 ± 6.15	693.11 ± 221.99	6.05 ± 1.79	23.15 ± 11.76
Tubulidentata	826.03 ± 0	33.55 ± 0	5.57 ± 0	61.2 ± 0	660.11 ± 0	6.12 ± 0	19.83 ± 0
Overall average	914.34 ± 175.51	48.73 ± 39.96	8.7 ± 6.47	61.14 ± 6.13	766.79 ± 407.66	6.27 ± 2.04	24.74 ± 9.8

Table 6. Sixteen Data Deficient taxa highlighted as having an above Threatened average Combined Human Threat (CHT) and their associated CHT rank.

Order	**Taxon**	**Common name**	**CHT value**	**CHT Rank**
Chiroptera	*Epomophorus gambianus crypturus*	Gambian epauletted fruit bat	982.4886	121
Chiroptera	*Hipposideros caffer*	Sundevall's leaf-nosed bat	1003.185	129
Insectivora	*Amblysomus hottentotus*	Hottentot's golden mole	1076.838	18
Insectivora	*Crocidura flavescens*	Greater musk shrew	983.044	65
Insectivora	*Crocidura fuscomurina*	Tiny musk shrew	1004.341	109
Insectivora	*Crocidura mariquensis*	Swamp musk shrew	1078	24
Insectivora	*Myosorex cafer*	Dark-footed forest shrew	1161.554	8
Insectivora	*Myosorex varius*	Forest shrew	980.3984	71
Insectivora	*Suncus infinitesimus*	Least dwarf shrew	1071.421	17
Insectivora	*Suncus lixus*	Greater dwarf shrew	1047.066	74
Rodentia	*Grammomys cometes*	Mozambique woodland mouse	1082.664	58
Rodentia	*Grammomys dolichurus*	Woodland mouse	1053.83	35
Rodentia	*Graphiurus platyops*	Rock dormouse	1042.439	73
Rodentia	*Lemniscomys rosalia*	Single-striped mouse	1053.89	56
Rodentia	*Mus neavei*	Thomas' pygmy mouse	1259.392	10
Rodentia	*Mus orangiae*	Free state pygmy mouse	1115.644	67

Discussion

Anthropogenic measures

Much of southern Africa has undergone extensive land transformation (Macdonald 1991; Deacon 1992; van Rensburg et al. 2004a), through agricultural development, urbanization, mining, as well as alien plant encroachment (Deacon 1992; Rebelo 1992; Richardson et al. 1996). Over the past 350 years, humans have preferred to settle in the Cape Floristic Region (CFR). These parts are known for the high concentration of endemic mammals (Siegfried & Brown 1992). Being predominantly present in winter rainfall Fynbos and Succullent Karoo Biomes (Cowling & Hilton-Taylor 1994). Siegfried & Brown (1992) reported that several mammals endemic to the south western parts of the country, such as the Riverine rabbit (*Bunolagus monticularis*), Van Zyl's Golden mole (*Cryptochloris zyli*), the Cape Mountain Zebra (*Equus zebra zebra*), and the Bontebok (*Damaliscus pygargus pygargus*) were also highly threatened. The CFR region also represents an area that has witnessed the greatest regional, mammal extinctions in South Africa, mainly human-induced (Rebelo 1992, Mckinney 2001). Each of South Africa’s nine provinces has a unique set of characteristic natural resources, human demands, infrastructure provision, levels of urbanization, economic structure, and performance (Development Bank of South Africa (DBSA) 2000).

Relationship between mammals and human activity measures

Anthropogenic activities form a complex web of threats that is influenced by various socio-economic and political factors (e.g. national policies, economic conditions and a host of other factors varying among nations; Macdonald 1991; James 1994; Kerr & Currie 1995; Development Bank South Africa 2000; McKinney 2001; O’Neill et al. 2001; Liu et al. 2003). Clear evidence for these separate components affecting taxon extinction have been highlighted, yet it is difficult to assign a single risk value to separate impacts of these measures (Kerr & Currie 1995; Chertow 2001; Ceballos & Ehrlich 2002). Furthermore using certain human threat predictors (as used in the current study) should not be taken to mean that other human impacts are insignificant, as many additional human activities are also extremely important at local scales e.g. agriculture, alien invasive species etc. (Macdonald 1991).

The present study indicates an association/congruence between most of the anthropogenic variables with overall mammal richness (OMR), yet very little of the variation in OMR was explained by the anthropogenic variables. In addition, weak correlations were also evident between EMR, TMR and various anthropogenic variables. Other studies indicated significant, but weak relationships between human population density, human population growth, poverty, per capita income, urbanization and mammals per country (Ehrlich & Holden 1971; Kerr & Currrie 1995; Harcourt & Parks 2003, Cincotta et al. 2000; McKee et al 2003). For example, Balmford et al. (2001) found a marked congruence between high vertebrate richness and human population density across Africa, while Chown et al. (2003) found a strong significant positive relationship between South African bird richness and human population density at a quarter degree scale. However, none of the six anthropogenic variables considered in the present study showed similar relationships with any of the measures of mammal richness despite some significant degrees of correlation.

Andrews & O'Brien (2000) reported a strong association between mammal and plant richness, with woody plant richness explaining between 70 – 77% of the mammal richness in southern Africa. Strong evidence indicates that primary productivity, evapotranspiration, and annual precipitation are some factors driving plant richness patterns (see O'Brien et al. 1998; Rutherford & Westfall 1986; O'Brien et al. 2000; Hawkins et al. 2003). Mammal richness is most likely defined by plant richness, which in turn is characterized by water-energy dynamics (Andrews & O'Brien 2000; Hawkins et al. 2003). Similarly, it has been shown that human population density and subsequent human predictors respond positively to increases in net primary productivity, indicating a relationship between measures of human and vertebrate richness (Balmford et al. 2001; Chown et al. 2003; Hawkins et al. 2003; van Rensburg et al. 2004b). These findings seem to support our results that allude to similar responses by measures of both human density and mammal richness being concurrent with primary productivity (Chown et al. 2003), with both high mammal richness and human distribution prevalent in the southern and eastern parts of the country.

The results from the current study suggest human threats do not currently define any of the mammal richness measures, with landscape transformation possibly being too recent to exhibit any statistically noticeable effect (Chown et al. 2003) at a QDS scale. processes that define mammal richness as well as threats may be operating at a finer spatial scale, over a longer temporal scale or, other more important causal mechanisms may dominate the current patterns, e.g. climatic variables, topographic variables, β-diversity etc. (Bailey et al. 2002, Hawkins & Pausas 2004). In addition, further analyses are required to ascertain which of the current human impact measures included in the current study are proximate or ultimate threats. It has been shown that human density is clearly a proximate threat with agriculture, urbanization, land transformation, and roads denoted as ultimate threats (Thompson & Jones 1999). A clearer understanding to which threats are more relevant as an immediate threat will allow relevant actions to be implemented.

A serious dilemma with the current analyses are attributable to the different varying spatial scales of the data used. Most of the anthropogenic data were collected at municipality level and were consequently transformed to QDS scale with most measures calculated as weighted averages, which resulted in a possible loss of fine scale information. Taxon distribution data (in this case mammal data) are rarely representative and accurate, and in most cases old and out of date (Freitag & van Jaarsveld 1995; Lombard 1995; Maddock & Benn 2000; Maddock & Samways 2000). South African mammal distribution data (presence and extent of occurrence data) are not equally sampled, incomplete and uneven in coverage and most of all at the wrong scale quarter degree scale (QDS) (Rebelo 1994; Freitag & van Jaarsveld 1995; Lombard 1995). This scale is often too coarse to reflect finer scale topographical and vegetation differences and will most likely fail to pick up many of the finer interactions between human predictors and mammal richness measures (Rebelo & Tansley 1993; van Rensburg et al. 2004a).

Another major factor influencing statistical results and analysis is the marked differences between the temporal scales of all the databases. The mammal QDS data range from specimens collected in the early 1900's up to present time (Freitag & van Jaarsveld 1995); with the additional distribution range maps also based on potential distribution ranges of species (Freitag & van Jaarsveld 1995). Conversely the anthropogenic variables used in the current study generally dates from 1994 to present. The discrepancy between the varying time lines of the data sources could be a plausible cause for the resulting poor statistical correlations and variation found within the current study.

It is possible that the limited difference detected in the analysis of the recommended measures of richness (Rebelo & Tansley 1993; Freitag & van Jaarsveld 1995, 1997; Chown et al. 2003, van Rendburg et al. 2004)) reflects the OMR measure that also include EMR and TMR mammals. It is also possible that further insight will be gained if additional measures representing ubiquitous taxa are included in this kind of analysis in future studies

Anthropogenic variables as threat proxy

The IUCN Red List is a well established and a widely accepted technique for assessing a taxon's probability of going extinct in the near future. It is based on quantitative data e.g., the taxon's' population size, rate of population decline, and its geographic range. By using the Red List, one gains an understanding of the taxon's probability of going extinct. However to fully understand a species' exact priority for conservation, one has to include a measure of threat. Harcourt and Parks (2003) found human density to be a reasonably good threat predictor, and yet some evidence suggests that human density alone may be a rather poor predictor of threat in certain taxonomic groups (Woodroffe 2000; Manne & Pimm 2001). The inclusion of additional anthropogenic demographic measures functioned well as threat predictors, with the data being up to date and easily accessible.

Threatened taxa seem to experience higher human density in their geographic range than do the non-Threatened taxa throughout their range in South Africa. On the contrary, the average combined human threat (CHT) and human change (HC) for DD taxa were all above that of threatened taxa. Harcourt & Parks (2003) suggests that such a measure can be used to highlight DD taxa that may be facing some severe human threat. Sixteen of the DD taxa can be regarded as provisionally Threatened (Table 6), with most of these taxa representing the Orders Rodentia, Insectivora and Chiroptera. These Orders were shown to be highly threatened according to the regional IUCN Red List (Chapter 2; Friedmann & Daly 2004), and are often under represented in conservation priorities and assessments (Chapter 2, Chapter 4; Entwistle & Stephenson 2000).

The largest and heaviest mammal in the top 50 CHT ranked mammals was the Blesbok *Damaliscus pygargus phillipsi*. The lower CHT ranks, which were assigned to mainly the larger bodied taxa, can most likely be attributed to most of the larger taxa experiencing lower human impact as they are limited to nature reserves, parks, and game farms (Freitag & van Jaarsveld 1995). Therefore these mammals would not be found in areas of high CHT measured ranks (Entwistle & Stephenson 2000), although evidence indicates that reserves are going to be under more human related pressures in the future (Balmford et al. 2001; Harcourt et al. 2001; Hansen & Rotella 2002). An analysis excluding data from conservation areas did not reveal any significant different CHT rankings (Keith. unpubl data), and did not reflect more accurate threats to species outside of these conservation areas.

Furthermore some of the highly threatened taxa for example the riverine rabbit, *Bunolagus monticularis* (CR C2a(i), E) and Visagie's golden mole, *Chrysochloris visagiei* (CR D) yielded very low CHT rankings due to low human threat measures, as these taxa are situated in low human impacted areas, for which was measured in the current study. Despite this, these taxa remained highly threatened due to their inherent life history traits making them more prone to extinction (Gaston 1998). Not only do these threatened taxa remain highly susceptible to extinction, but should a new threat (e.g. new land use practises) come into play these taxa would experience increased threat or extinction.

When using human variables to predict possible threats to mammals, one should keep in mind that there might be several "weedy" taxa or generalist as indicated by Harcourt and Parks (2003). It is known that various taxa react differently to the same threat, and additionally with the use of various human demographic variables to indicate potential risk, a concern is that that various taxa which benefit, or associate with certain human altered habitats will be considered as experiencing "high" human risk. Such "weedy" taxa (Harcourt & Parks 2003) (e.g. woodland mouse *Grammomys dolichurus*, and red duiker, *Cephalophus natalensis*) function well and often favour human altered environments (de la Peña et al. 2003). Yet as Harcourt & Parks (2003) indicate, such "weedy" taxa may be under considerable human threat and can still face extinction if certain detrimental conditions are met.

Conclusion

The conservation movement today, sets conservation targets by incorporating a wide variety of suitable data, ranging from taxa/species information, land types and habitat types, and various forms of threats (Pressey et al. 2003). Incorporating anthropogenic measures into threat assessments of mammals does allow for additional perspectives to the conservation prioritisation of inherently higher threatened taxa due to human impact and threats (Harcourt & Parks 2003).Yet it is imperative that we obtain a better understanding of the relationship between the different variables used in the current study. Furthermore we fully acknowledge the shortcomings of the mammal distribution data, and the use thereof in the current study are a "necessary evil" (Freitag et al. 1998). The combination of presence and distribution range maps as used in the current study have hopefully proven to be effective in representing mammal biodiversity, circumventing current data constraints (Freitag & van Jaarsveld 1995; Gelderblom & Bronner 1995).

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References

Andrews, P. and E. M. O'Brien. 2000. Climate, vegetation, and predictable gradients in mammal species richness in southern Africa. Journal of Zoology, London **251**: 205-231.

Araújo, M. B. 2003. The coincidence of people and biodiversity in Europe. Global Ecology and Biogeography **12**: 5-12 .

Bailey, S.-A., R. H. Haines-Young, and C. Watkins. 2002. Species presence in fragmented landscapes: modelling of species requirements at the national level. Biological Conservation **108**: 307-316.

Balmford, A., J. L. Moore, T. Brooks, N. Burgess, L. A. Hansen, P. Williams, and C. Rahbek. 2001. Conservation conflicts across Africa. Science **291**: 2626.

Burgess, N. D., C. Rahbek, F. W. Larsen, P. Williams, and A. Balmford. 2002. How much of the vertebrate diversity of sub-Saharan Africa is catered for by recent conservation proposals? Biological Conservation **107**: 327-339.

Ceballos, G. and P. R. Ehrlich. 2002. Mammal population losses and the extinction crisis. Science **296**: 904-907.

Central Statistical Service. 1995. Gross Geographic Product 1994. Statistical release P0401. Central Statistical Service , Pretoria, Republic of South Africa.

Central Statistical Service. 1998. The people of South Africa. Population census, 1996. Report No. 1: 03-01-11. Central Statistical Survey, Pretoria, Republic of South Africa.

Chertow, M. R. 2001. The IPAT equations and its variants. Changing views of technology and environmental impact. Journal of Applied Ecology **4**: 13-29.

Chown, S. L., B. J. van Rensburg, K. J. Gaston, A. S. L. Rodriquez, and A. S. van Jaarsveld. 2003. Energy, species richness, and human population size: conservation implications at a national scale.

Ecological Applications **13**: 1233-1241.

Cincotta, R. P., J. Wisnewski, and R. Engelman. 2000. Human population in the biodiversity hotspots. Nature **404**: 990-992.

Cowling, R. M. and C. Hilton-Taylor. 1994. Patterns of plant diversity and endemism in southern Africa: an overview. Pages 31-52 in B.J. Huntley, editors. Botanical diversity in southern Africa. Sterlitzia 1, National Botanical Institute Pretoria. F

de la Peña, N. M., A. Butet, Y. Delettre, G. Paillat, P. Morant, L. Le Du, and F. Burel. 2003. Response of the small mammal community to changes in western French agricultural landscapes. Landscape Ecology **18**: 265–278.

Deacon, H. J. 1992. Human settlement. Pages 260-270 in R.M. Cowling, editors. The ecology of fynbos. Nutrients, fire and diversity. Oxford University Press, Oxford, U.K.

Development Bank of South Africa (DBSA). 2000. South Africa: Inter-provincial comparative report. Development Bank of South Africa., Halfway House South Africa.

Ehrlich, P. R. and Holdren J.P. 1971. Impact of population growth. Science **171**: 1212-1217.

Entwistle, A. and P. J. Stephenson. 2000. Small mammals and the conservation agenda. Pages 119-139 in A. Entwistle and N. Dunstone, editors. Priorities for the conservation of mammalian diversity. Has the panda had its day? Cambridge University Press, Cambridge, United Kingdom.

Fairbanks, D. H. K. and M. W. Thompson. 1996. Assessing land-cover map accuracy for the South African land-cover database. South African Journal of Science **96**: 69-82.

Fairbanks, D. H. K., M. W. Thompson, D. E. Vink, T. S. Newby, H. M. van den Berg, and D. A. Everard. 2000. The South African land-cover characteristics database: a synopsis of the landscape. South African Journal of Science **96**: 69-82.

Fjeldså, J. 2000. The relevance of systematics in choosing priority areas for global conservation. Environmental Conservation **27**: 67-75.

Freitag, S. and A. S. van Jaarsveld. 1995. Towards conserving regional mammalian species diversity: a case study and data critique. South African Journal of Zoology **30**: 136-143.

Freitag, S., A. O. Nicholls, and A. S. van Jaarsveld. 1998. Dealing with established reserve networks and incomplete distribution data sets in conservation planning. South African Journal of Science **94**: 79-86.

Friedmann Y. and D. Daly. 2004. Red Data Book of the Mammals of South Africa: A Conservation Assessment. CBSG Southern Africa, Conservation Breeding Specialist Group (SSC/IUCN), Endangered Wildlife Trust. South Africa.

Gaston, K. J. 1998. Rarity as double jeopardy. Nature **394**: 229-230.

Gelderblom, C. M. and G. N. Bronner. 1995. Patterns of distribution and protection status of endemic mammals in South Africa. South African Journal of Zoology **30**: 127-135.

Gelderblom, C. M., B. N. Bronner, A. T. Lombard, and P. J. Taylor. 1995. Patterns of distribution and current protection status of the Carnivora, Chiroptera and Insectivora in South Africa. South African Journal of Zoology **30**: 103-114.

Hanks, J. 2000. The role of Transfrontier Conservation Areas in southern Africa in the conservation of mammalian diversity. Pages 239-256 in A. Entwistle and N. Dunstone , editors. Priorities for the conservation of mammalian diversity. Has the panda had its day? Cambridge University Press, Cambridge, United Kingdom.

Hannah, L., D. Lohse, C. Hutchinson, J. H. Carr, and A. Lankerani. 1994. A preliminary inventory of human disturbance of world ecosystems. Ambio **23**: 246-250.

Hansen, A. J. and J. J. Rotella. 2002. Biophysical factors, land use and species viability in and around nature reserves. Conservation Biology **16**: 1112-1122.

Harcourt, A. H. and S. A. Parks. 2003. Threatened primates experience high human densities: adding an index of threat to the IUCN Red List criteria. Biological Conservation **109**: 137-149.

Harcourt, A. H., S. A. Parks, and R. Woodroffe. 2001. Human density as an influence on species/area relationships: double jeopardy for small African reserves? Biodiversity and Conservation **10**: 1011-

1026.

Hawkins, B. A. and J. G. Pausas. 2004. Does plant richness influence animal richness?: the mammals of Catalonia (NE Spain). Diversity and Distributions **10**: 247-252.

Hawkins, B., R. Field, H. V. Cornell, D. J. Currie, J.-F. Guégan, D. M. Kaufman, J. T. Kerr, G. G. Mittelbach, T. Oberdorff, E. M. O'Brien, E. E. Porter, and J. G. Turner. 2003. Energy, Water, and Broad-Scale Geographic Patterns of Species Richness. Ecology **84**: 3105–3117.

IUCN. 2001. IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission. IUCN, IUCN, Gland, Switzerland and Cambridge, UK.

James, V. U. 1994. Introduction: The significance of economic and environmental impact studies in Africa's developement. Pages 1-14 in V.U. James, editors. Environmental and economic dilemmas of developing countries: Africa in the twenty-first century. Praeger Publisher, Westport, USA.

Keith, M., 2004. Geographic Information System (GIS) data of South African mammals. Available from: http://zoology.up.ac.za/samammals/ (accessed 22 September 2004).

Kerr, J. T. and D. J. Currie. 1995. Effects of human activity on global extinction risk. Conservation Biology **9**: 1528-1538.

Liu, J., G. C. Daily, P. R. Ehrlich, and G. W. Luck. 2003. Effects of household dynamics on resource consumption and biodiversity. Nature **421**: 530-533.

Lombard, A. T. 1995. Introduction to an evaluation of the protection status of South Africa's vertebrates. South African Journal of Zoology **30**: 63-70.

Lucas, G. and H. Synge. 1981. The assessment of conservation of threatened plants around the world. Pages 3-19 in H. Synge, editors. The biological aspects of rare plant conservation. John Wiley & Sons, London.

Luck, G. W., T. H. Ricketts, G. C. Daily, and M. Imhoff. 2003. Alleviating spatial conflict between people and biodiversity. Proceedings of the National Academy of Sciences **101**: 182-186.

Macdonald, I. A. W. 1991. Man's role in changing the face of southern Africa. Pages 136-147 in B.J.

Huntley, editors. Biotic diversity in Southern Africa: concepts and conservation. Oxford University Press, Cape Town.

Maddock, A. and G. A. Benn. 2000. Identification of conservation-worthy area in northern Zululand, South Africa. Conservation Biology **14**: 155-166.

Maddock, A. H. and M. J. Samways. 2000. Planning biodiversity conservation based on the knowledge of biologists. Biodiversity and Conservation **9**: 1153-1169.

Maggini, R., A. Guisan, and D. Cherix. 2002. A stratified approach for modelling the distribution of a threatened ant species in the Swiss National Park. Biodiversity and Conservation **11**: 2117-2141.

Manne, L. L. and S. L. Pimm. 2001. Beyond eight forms of rarity: which species are threatened and will they be next? Animal Conservation **4**: 221-229.

McCullagh, P. and J. A. Nelder. 1989. Generalized Linear Models. Chapman & Hall, London.

McKee, J. K., P. W. Sciulli, C. D. Fooce, and T. A. Waite. 2003. Forecasting global biodiversity threats associated with human population growth. Biological Conservation **115**: 161-164.

McKinney, M. L. 2001. Role of human population size in raising bird and mammal threat among nations. Animal Conservation **4**: 45-57.

Melles, S., S. Glenn, and Martin K. 2003. Urban bird diversity and landscape complexity: Species environment associations along a multiscale habitat gradient. Conservation Ecology **7**: 5. [online] URL: http://www.consecol.org/vol7/iss1/art5.

Mills, M. G. L., S. Freitag, and A. S. van Jaarsveld. 2001. Geographic priorities for carnivore conservation in Africa. Pages 467-483 in J.L. Gittleman, S. M. Funk, D.W. Macdonald, and R. K. Wayne, editors. Carnivore Conservation. Cambridge University Press, Cambridge.

Naidoo, R. and W. L. Adamowicz. 2001. Effects of economic prosperity on numbers of threatened species. Conservation Biology **15**: 1021-1029.

O'Brien, E. M., R. Field, and R. J. Whittaker. 2000. Climatic gradients in woody plant (tree and shrub) diversity: water-energy dynamics, residual variation, and topography. Oikos **89**: 588-600.

O'Brien, E. M., R. J. Whittaker, and R. Field. 1998. Climate and woody plant diversity in southern Africa: relationships at species, genus and family levels. Ecography **21**: 495-509.

O'Neill, B. C., D. Balk, M. Brickman, and M. Ezra. 2001. A Guide to Global Population Projections. Demographic Research **4**: 204-288. www.demographic-research.org.

Pfab, M. F. and J. E. Victor. 2002. Threatened plants of Gauteng, South Africa. South African Journal of Botany **68**: 370-375.

Pressey, R. L., C. J. Humphries, C. R. Margules, R. I. Vane-Wright, and P. H. Williams. 1993. Beyond opportunism: key principles for systematic reserve selection. Trends in Ecology and Evolution **8**: 124-128.

Rebelo, A. G. 1992. Preservation of biotic diversity. Pages 309-344 in R.M. Cowling, editors. The ecology of fynbos. Nutrients, fire and diversity. Oxford University Press., Oxford, U.K.

Rebelo, A. G. 1994. Iterative selection procedures: centres of endemism and optimal placement of reserves. Pages 231-258 in B.J. Huntley, editors. Botanical diversity in southern Africa. Sterlitzia 1, National Botanical Institute Pretoria.

Rebelo, A. G. and S. A. Tansley. 1993. Using rare plant species to identify priority conservation areas in the Cape Floristic Region: the need to standardize for total species richness. South African Journal of Science **89**: 156-161.

Reyers, B. 2004. Incorporating anthropogenic threats into evaluations of regional biodiversity of conservation areas in the Limpopo Province, South Africa. Biological Conservation **118**: 521-531.

Reyers, B., D. H. K. Fairbanks, and A. S. van Jaarsveld. 2001. Priority areas for the conservation of South African vegetation: a coarse-filter approach. Diversity and Distributions **7**: 79-95.

Richardson, D. M., B. W. van Wilgen, S. I. Higgins, T. H. Trinder-Smith, R. M. Cowling, and D. H. McKell. 1996. Current and future threats to plant biodiversity on the Cape Peninsula, South Africa. Biodiversity and Conservation **5**: 607-647.

Rouget, M., B. Reyers, Z. Jonas, P. Desmet, A. Driver, K. Maze, B. Egoh, and R. M. Cowling. 2004.

South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 1:Terrestrial Component. South African National Biodiversity Institute, Pretoria.

Rouget, M., D. M. Richardson, R. M. Cowling, J. W. Lloyd, and A. T. Lombard. 2003. Current patterns of habitat transformation and future threats to biodiversity in terrestrial ecosystems of the Cape Floristic Region, South Africa. Biological Conservation **112**: 63-85.

Rutherford, M. C. and R. H. Westfall. 1986. Biomes of southern Africa – an objective categorization. Memoirs of the Botanical survey of South Africa. **54**: 1-98.

Siegfried, W. R. and C. A. Brown. 1992. The distribution and protection of mammals endemic to southern Africa. South African Journal of Wildlife Research **22**: 11-16.

Sisk, T. D., A. E. Launer, K. R. Switky, and P. R. Ehrlich. 1994. Identifying extinction threats; global analyses of the distribution of biodiversity and the expansion of the human enterprise. Bioscience **44**: 592-604.

Skinner, J. D. and R. H. N. Smithers. 1990. The mammals of the southern African subregion. University of Pretoria, Pretoria, South Africa.

StatSoft, Inc. 2001. STATISTICA (data analysis software system), version 6. www.statsoft.com.

Theobald, D. M. 2003. Targeting conservation action through assessment of protection and exurban threats. Conservation Biology **17**: 1624-1637.

Thompson, K. and A. Jones. 1999. Human population density and prediction of local plant extinction in Britain. Conservation Biology **13**: 185-189.

Ukpolo, V. 1994. The link between poverty and environmental degradation on sub-saharan Africa. Pages 69-80 in V.U. James, editors. Environmental and economic dilemmas of developing countries: Africa in the twenty-first century. Praeger Publisher, Westport, USA.

United Nations Development Programme South Africa. 2003. Oxford University Press, Southern Africa, Cape Town.

van Rensburg, B. J., B. F. N. Erasmus, A. S. van Jaarsveld, K. J. Gaston, and S. L. Chown. 2004a.

Conservation during times of change: correlations between birds, climate and people in South Africa. South African Journal of Science **100**: 266-272.

van Rensburg, B. J., P. Koleff, K. J. Gaston, and S. L. Chown. 2004b. Spatial congruence of ecological transition at the regional scale in South Africa. Journal of Biogeography **31**: 843-854.

van Jaarsveld, A. S., R. Biggs, R. J. Scholes, E. Bohensky, B. Reyers, L. Lynam, C. Musvoto, and C. Fabricius. 2005. Measuring conditions and trends in ecosystem services at multiple scales: the Southern African Millennium Ecosystem Assessment (SA*f*MA) experience. Philosophical Transactions of the Royal Society B **360**: 425-441.

Woodroffe, R. 2000. Predators and people: using human densities to interpret declines of large carnivores. Animal Conservation **3**: 165-173.

World Resources Institute. 2000. World Resources 2000-2001: People and ecosystems: The fraying web of life. World Resources Institute, Washington, D.C., USA.

Zar, J. H. 1996. Biostatistical analysis. Upper Saddle River Prentice-Hall, NJ.